

SIMULATING ENERGY MARKETS AND INFRASTRUCTURE INTERDEPENDENCIES WITH AGENT BASED MODELS

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ABSTRACT

National infrastructure systems are becoming more complex and interdependent. Markets and industries for electric power, natural gas, petroleum, and telecommunications are examples of physical infrastructures and markets that are undergoing rapid evolution. For example, energy power (EP) markets that have pioneered the transition from a regulated monopolistic system to decentralized open markets have faced many challenges. The restructuring of the natural gas (NG) industry is another example.

As the national infrastructures become more efficient, as safety margins narrow, and as systems approach their design limitations, infrastructures are becoming more interdependent in both economic and physical terms. Recently, breakdowns in the infrastructure markets and systems have become the object of the public's attention. The California electricity crisis and the natural gas price spike of December 2000 are examples. These incidents have the potential to create ripple effects in other infrastructures and raise important questions concerning the extent of infrastructure interdependencies:

- Is it possible to quantify the physical and economic interdependencies between the infrastructures?
- How long does it take for disruptions (physical and economic) in one infrastructure to propagate through another infrastructure (e.g., the time constant for electric power is near zero while for gas it is hours or days)?
- Under what conditions or system parameter values could amplification occur resulting in positive feedback, in which disruptions in one infrastructure cause another infrastructure to exhibit unstable behavior?
- How will the infrastructures adapt or can be made to adjust in response to shocks and disruptions?

The physics of the physical infrastructures (e.g., electric power generation and distribution) is well known; modeling is an implementation issue. The rules of business are at least as important as the rules of physics when it comes to the generation, sale, and

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delivery of electrical power, for example, as well as the other infrastructures. The decision-making behavior of firms in an industry and the financial vehicles that allow a utility to exist and conduct business are crucial to gaining an understanding of the system evolution.

Traditional simulation and optimization models are no longer adequate to answer important questions about the stability and robustness of the infrastructures and their potentially interdependent evolution. To a large extent, these systems have always been too complex to model adequately. For example, modeling economic markets has often relied on the notions of perfect markets, homogeneous agents, and long-run equilibrium. The need to capture transitory infrastructure system behaviors in response to shocks and disruptions is a key issue in infrastructure interdependency analysis. There is also an important need to understand the path of transitory states experienced by an infrastructure, which in turn affects its longer-run configuration. Agent Based Modeling and Simulation (ABMS) offers a more realistic modeling alternative to capture these aspects of the infrastructure.

ABMS is a fundamentally new approach to simulating systems. The decision processes and actions of individual agents (e.g., consumers, companies) are simulated, rather than the aggregate system behavior patterns and trends, as in traditional approaches. ABMS attempts to capture the complex, non-linear, self-organizing, emergent, and sometimes chaotic patterns of interaction exemplified by complex systems. Until recently, agent-based simulation was outside the reach of existing computational capability. Using an ABMS approach, the physical and behavioral aspects of the infrastructures are represented as a system of highly connected, interacting agents. Agents interact in terms of physical flows and by exchanging information on system performance; key economic parameters are essential to model realistic system operation and adaptation. Each agent has rules of behavior and a decision-making capability that broadly considers salient aspects of the immediate environment and other agents' behaviors. Organizations that control the various parts of the infrastructure and their decision-making behaviors are modeled explicitly as collections of agents or form spontaneously in response to the physical and economic environment.

This paper explores the use of agent-based modeling methodologies to simulate interactions among the interdependent infrastructures, focusing on the electric power and natural gas systems. A simulation of the diverse agents of the electric power and natural gas systems and their interaction in terms of the system properties (e.g., reliability, stability), market issues (e.g., pricing, market share patterns), and economic issues (e.g., electric company profitability, cost recovery) is presented. Modeling the decision processes and actions of the individual agents (e.g., natural gas suppliers, transmission companies, independent power producers) involved in the operation of, and use of the commodities provided by the infrastructures is the focus of the paper. Modeling infrastructure agent behaviors is informed by approaches to modeling agent behavior in being taken in the social sciences. Aspects of decision-making behavior included within the scope of modeling infrastructure agent behaviors include among others: (1) agents' selection of objective(s), (2) pricing and bidding strategies, (3) learning and adaptation, and (4) capacity expansion decisions.